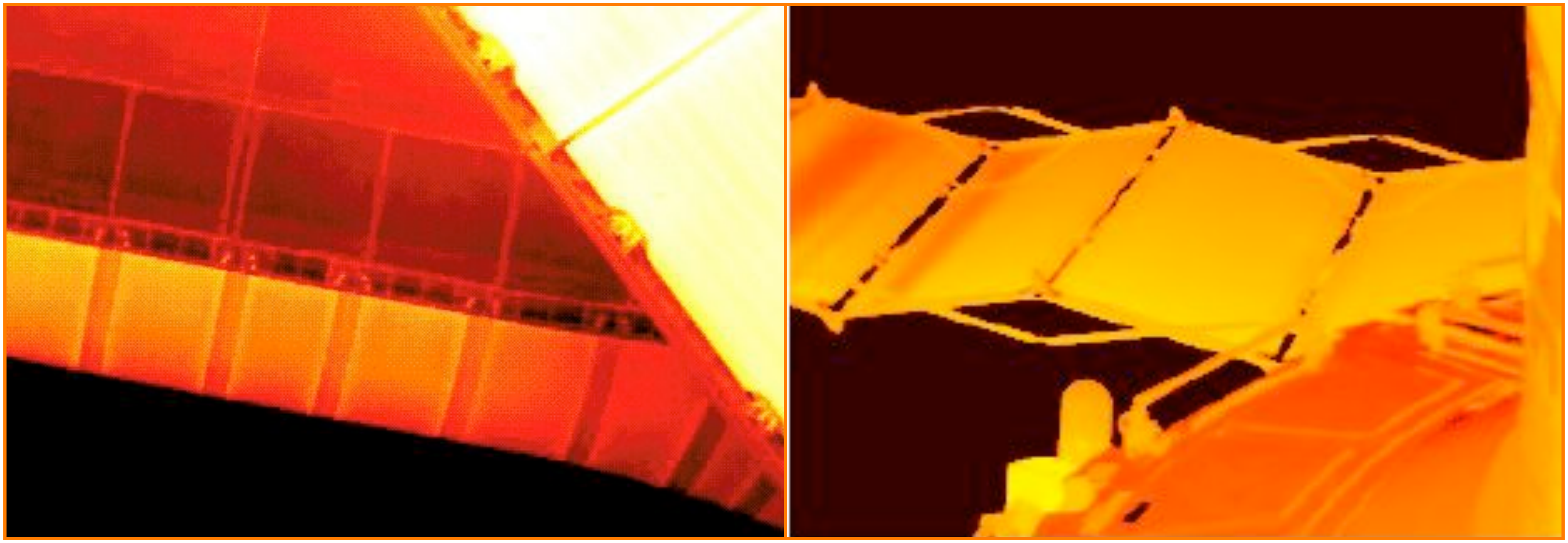
ETDP—Advanced Thermal Project

Thermal Control System for Exploration



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Outline

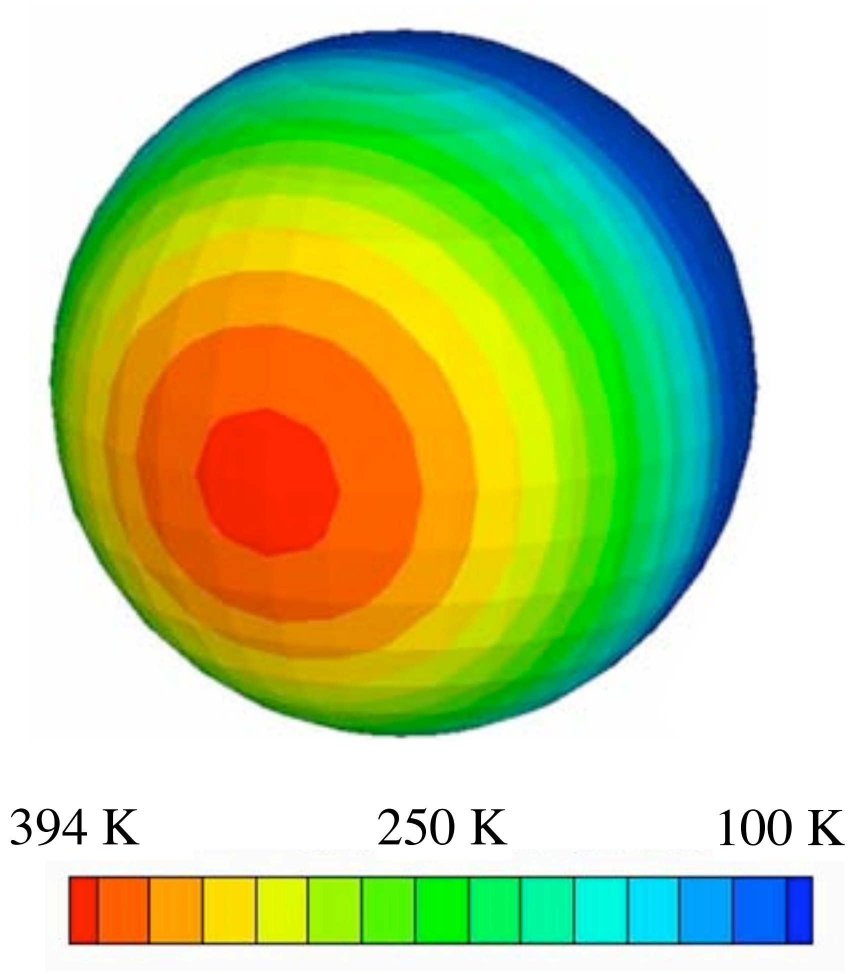
ETDP—Advanced Thermal Project

- Thermal technology challenges for upcoming projects
  - Crew Exploration Vehicle (CEV)
  - Lunar Lander
  - Lunar Surface Systems (Outpost, Rovers, ISRU, etc…)
- Current in-house technology development effort overview
- Discussion

CEV

- Largest thermal challenge for CEV is heat rejection in low Lunar orbit
- Surface of the moon is cold... and hot
- Current 100 km orbital altitude gives wide variation of sink temperature
- Need for increased thermal capacitance
  - phase change heat exchanger

Lunar Surface Temperatures



Apollo Always Landed *in the Morning*

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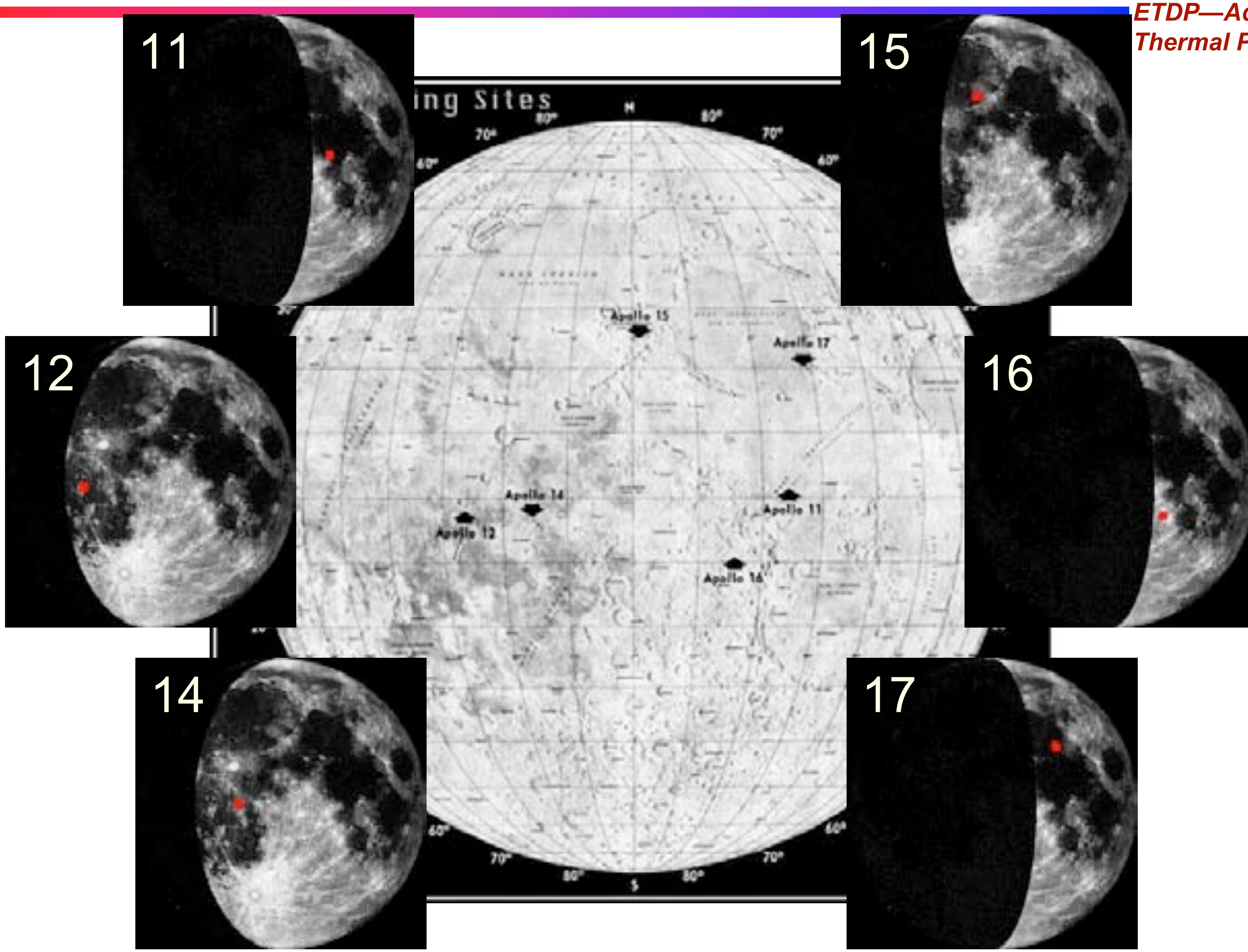

Orbital Sink Temperatures

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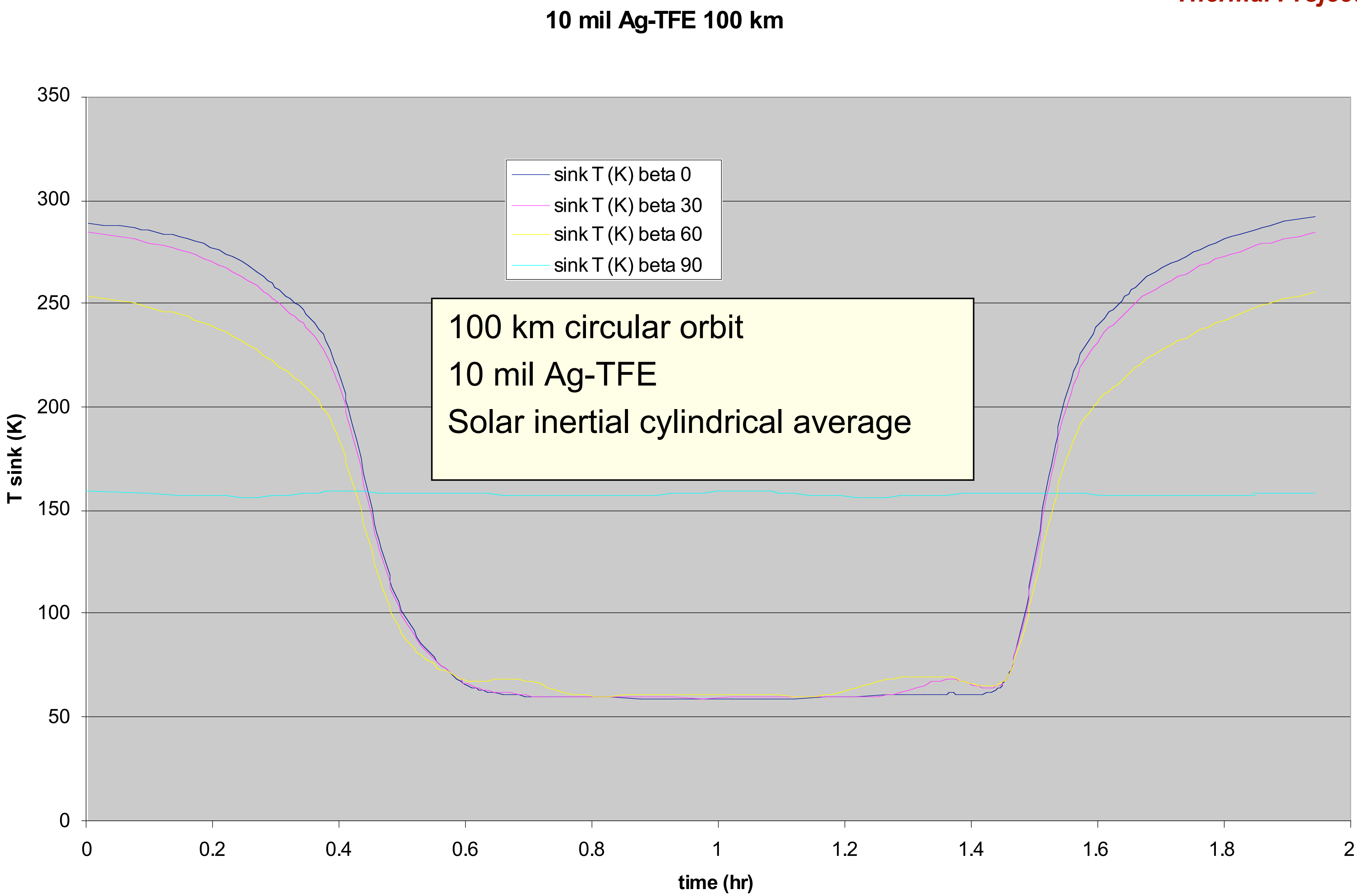

Lunar Lander Characteristics - Thermal

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- Lander is analogous to Apollo Lunar Module
  - Large combined vehicle descends to surface
  - Small ascent module returns to Crew Exploration Vehicle (CEV)
- Characteristic Lander dimensions
  - ~7 m diameter
  - ~10 m height
- Mission length
  - ≥ 14 day LEO dwell with Earth Departure Stage (EDS)
  - 3 day trans-Lunar coast with CEV
  - 7 days on Lunar surface
  - 3 hour nominal return to CEV

Lander Thermal Design Space

- Lander is not activated until 24 hours before Lunar orbit insertion
- Power is available prior to activation
  - ~600 W in low Earth orbit from EDS
  - ~1.5 kW in transit from CEV
- Nominal heat loads
  - <1 kW before activation in trans-Lunar coast
  - ~5 kW after activation prior to descent
  - ~5 kW on surface
  - ~2 kW during ascent

Lander Thermal Design Space

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- Radiator environments
  - deep space in trans-Lunar coast
  - at south pole landing site
    - assume ~5° ground angle at landing site with maximum sun
    - $1/\pi$ view factor of radiators to sun
    - results in 214 K sink for 10 mil silver-Teflon
  - equatorial landing site would result in surface temperature of up to 394 K plus full sun
    - results in 325 K sink for upright 10 mil silver-Teflon

Lander Active Thermal System Challenges

- Very cold sink temperatures
  - Deep space sink at low heat load
    - avoid radiator freezing
- Detailed radiator/terrain interaction
- Large required turndown ratio
  - Lowest heat load occurs in coldest environment
  - Additional heater power is available, but its use should be minimized
- Mass, mass, mass

Lunar Outpost Thermal Characteristics

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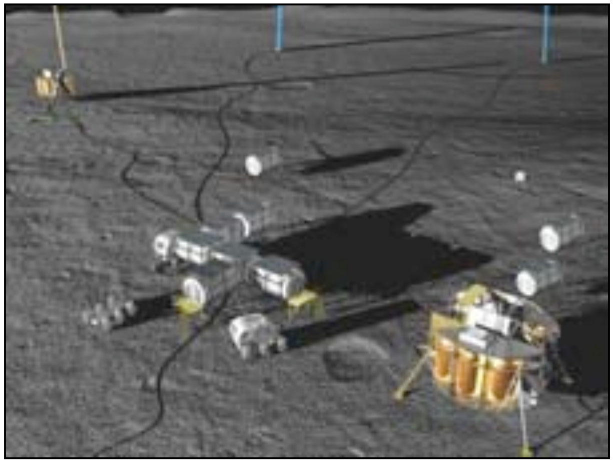
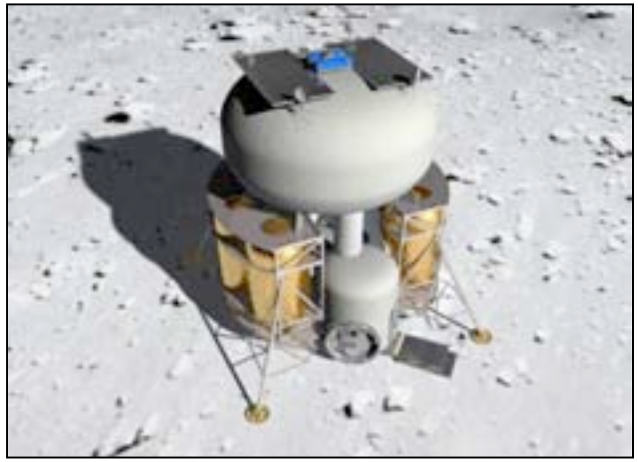


- Most likely site is Lunar south pole
  - Still investigating mobile habitats
- 4 crewmembers
- 7 month crew rotations
- 10 – 15 kW heat rejection requirement

Outpost Active Thermal System Challenges

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- Large required turndown ratio for unoccupied periods
- Extremely cold sink temperatures
  - Avoid radiator freeze
  - fluid life issues – contamination & corrosion
- Potential extended periods of no sun (days)
- Radiator design – Lander challenges plus...
  - Impact of dust accumulation
    - added resistance and increased absorptivity
    - or mitigation
- Robotics
- Rovers
  - more complex than Apollo
  - may include self contained habitats
- Mass, mass, mass

Advanced Thermal Project WBS

ETDP—Advanced Thermal Project

2.0 TCS Fluids	3.0 Heat Acquisition	4.0 Evaporative Heat Sinks	5.0 Radiator	6.0 System Design & Testing	7.0 Two-Phase Systems
2.1 TCS Fluids Test Bed	3.1 Sublimator Driven Coldplate	4.1 Evaporative Cooling Trade Study	5.1 Variable Heat Rejection Radiators	6.1 System Design	7.1 Ice PCM Development
	3.2 Composite Heat Exchangers & Coldplates		5.2 Regolith Effects & Mitigation	6.2 System Testing	7.2 Orion Energy Storage Heat Exchanger
			5.3 LSAM Radiator	6.3 ETDP Collaboration	7.3 Vapor Compression Heat Pump
			5.4 Outpost Radiator	6.4 Component Testing	

2.0 TCS Fluids

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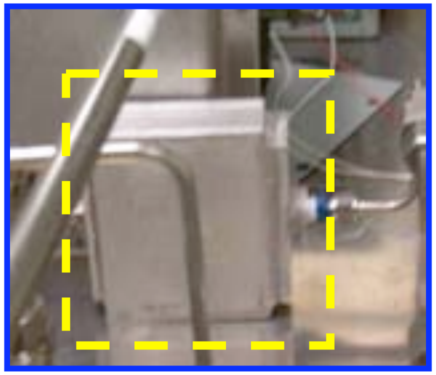
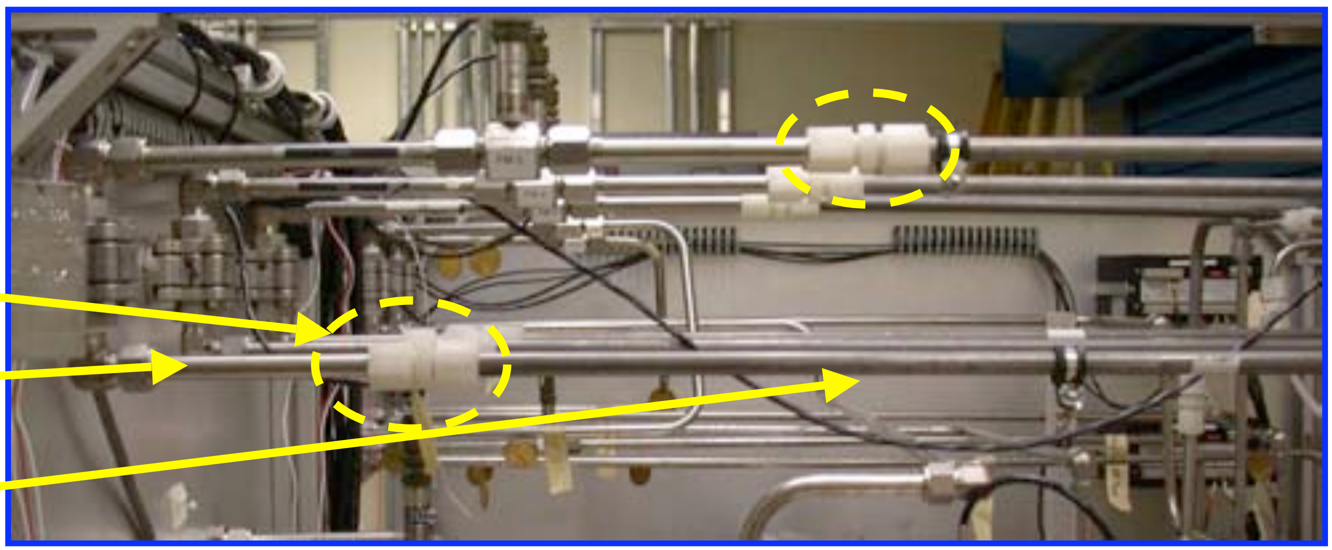


Aluminum Heat Exchanger

Boroscope View

- Long duration materials compatibility data is needed for Orion, Lunar Lander, and Outpost
  - Especially important for aluminum components and systems with dissimilar metals
- It is desirable to use the same heat transport fluid for as many CxP applications as possible
- Continue to run the TCS fluids test bed and report quarterly
  - Fluid samples and heat exchanger/tubing inspection



3.0 Heat Acquisition

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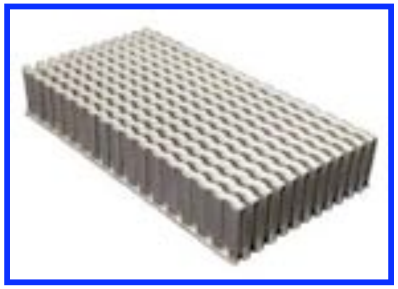
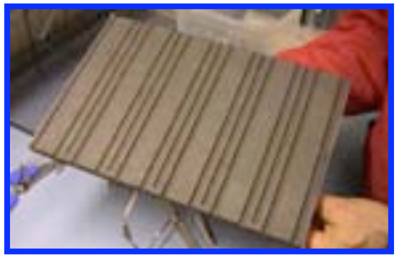
- Heat acquisition hardware collects energy from sources such as the crew and avionics then transfers it to the TCS
- Traditional heat acquisition hardware consists of air-liquid heat exchangers, liquid-liquid heat exchangers, and coldplates
  - **Sublimator Driven Coldplate (SDC)**
    - Revolutionary single unit that combines functions of a coldplate, sublimator, and fluid loop
    - Eliminates the need for a pumped fluid loop which decreases system mass and complexity and eliminates TCS power
    - Targeted at 1 – 2 kW systems with short transport distances, primarily lunar lander ascent stage
  - **Composite Heat Exchangers and Coldplates**
    - ETDP advanced thermal project has already made efforts to develop composite radiators
    - Extend the radiator lessons-learned to coldplates and heat exchangers to realize mass savings through desirable material properties
      - High thermal conductivity
      - High strength to mass ratio

Air/Liquid HX

Heat Transfer Fins



Graphite Foam



4.0 Evaporative Heat Sinks

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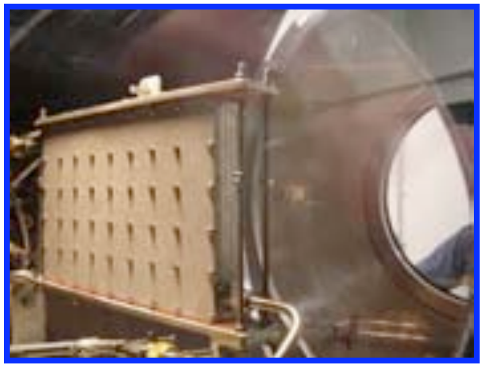
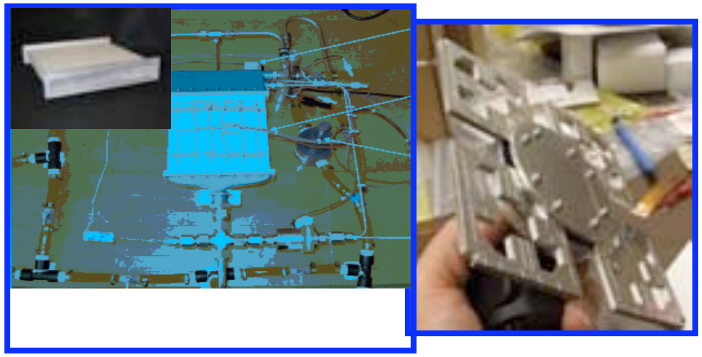
- Reject energy by evaporating and venting a fluid
- Typically used for short duration heat rejection due to consumable fluid
- ETDP advanced thermal project has developed 3 evaporators:
  - Contaminant Insensitive Sublimator (CIS)
  - Multi-environment Evaporative Heat Sink (MEHS)
  - Compact Flash Evaporator (CFES)
- Future Plans
  - Test the 3 evaporators
  - Identify potential CxP evaporator needs (rover, ascent module, suit, etc…) and requirements
  - Perform trade study & continue development



CIS Engineering Unit Test

MEHS with Vapor Header and Orifice



CFES Heat Exchanger and Spray Assembly

5.0 Radiator

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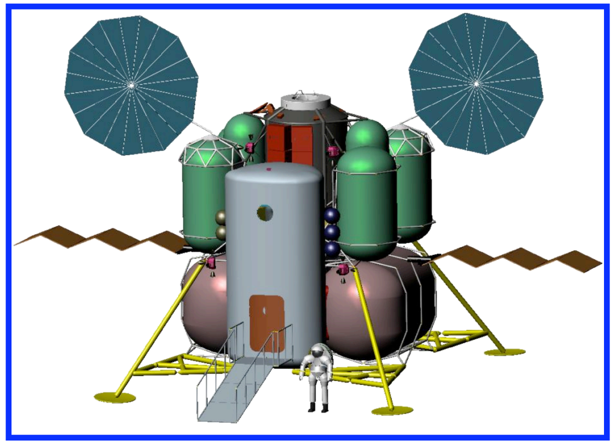
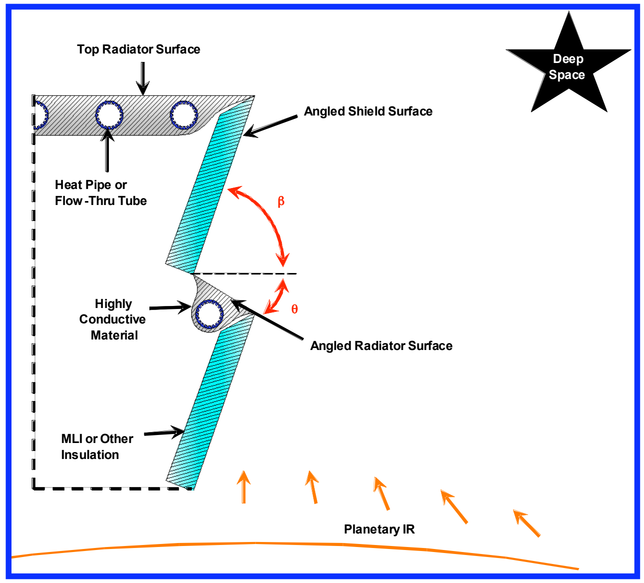
- Radiator design for landers and outposts pose never before experienced challenges
  - Extremely cold "sink temperatures" in transit and at the poles
  - Small heat rejection requirement in transit and large heat rejection requirement during lunar operations
  - Large day-night temperature swings at equatorial locations
  - Limited surface area on the vehicles for mounting panels
  - Complex radiation environment that includes lunar surface participation
- Major Tasks
  - Active thermal control coatings
  - Effects of lunar dust and mitigation strategies
  - Lander Radiator Development
    - Trades for radiator geometries, coatings, materials, flow configurations, and deployment mechanisms
  - Outpost Radiator Development



Deployable Radiator



Saw toothed Radiator Design

6.0 System Design & Testing

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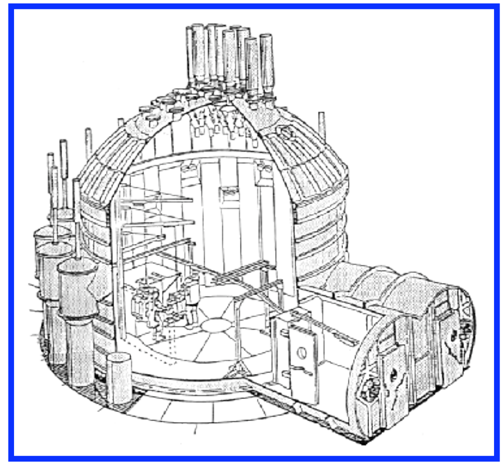
- FY 07 – Complete the Orion technology integrated test
  - PCM integration
  - Check out for thermal control system control scheme
  - Currently there are no plans for an Orion integrated test
- F 08 – System Analysis and Trades
  - Perform system trades to identify promising technologies for Lunar Lander
  - Perform research and system trade study to identify potential thermal hardware needs in ISRU, robotic, and lunar rover systems
- FY 09 – Component reliability study
  - Components like valves, relief valves, and quick disconnects are the cause of a large percentage of on-orbit TCS issues
  - Research and develop life tests for problem prone components
  - Hardware development work may be a follow on task based on findings
  - Especially critical for assembling fluid systems in dusty environments



Chamber B (JSC)

7.0 Two-Phase Systems

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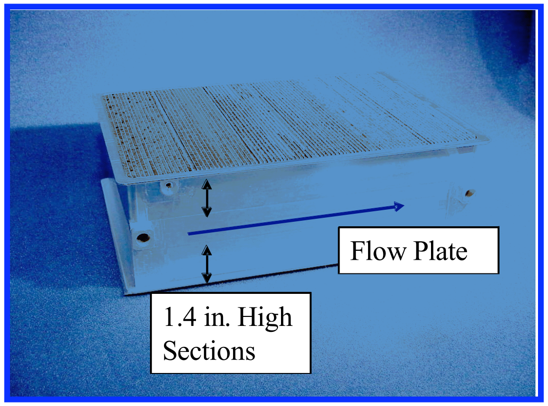
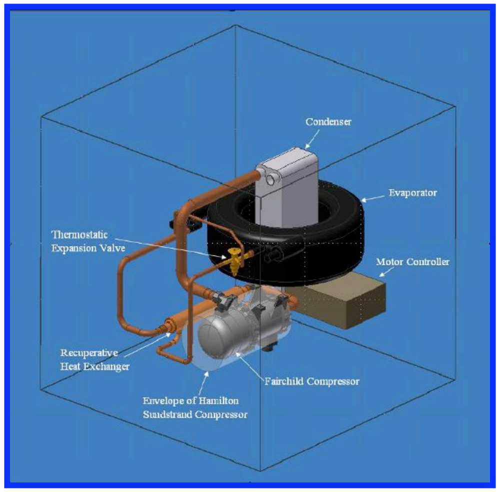
- **Ice PCM development**
  - Much higher heat of fusion (less mass) than wax PCM's
  - Technical challenge with expansion/contraction of material and selection of interstitial materials
- **PCM life test**
  - Orion is baselining use of wax pcm
  - Use of pcm has been identified as a top 10 risk by the Orion vehicle integration office
  - Life test will consist of at least 2500 freeze/thaw cycles
- **Heat Pump**
  - ETDP advanced thermal project has performed work for 15 kW heat pump
  - Most likely application for heat pump is anytime/anywhere lunar lander (~ 5 kW)
  - Will design a 5 kW heat pump…results will used in a heat pump trade study





Discussion

- Clarification?
- Identification of holes
- Possible complementary IR&D